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Safety performance monitoring and measurement of civil aviation unit

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ABSTRACT

A method of safety performance measurement is proposed to monitor the safety management process of civil aviation unit (CAU) with a series of safety performance indicators (SPIs). All these SPIs are arranged in a three-level model based on the analytic hierarchy process (AHP) and Delphi method, called the DAHP model, which takes full advantage of the expert knowledge and quantitative calculation. The weight of each SPI is estimated by the DAHP model, while its score is monitored and measured quantitatively with the two values of the standard deviation and average values of the preceding historical data points. The proposed method was tested successfully on the real data of a regional CAU in China, reflecting the CAU's safety management state immediately and quantitatively.

1. Introduction

Safety has always been the most significant issue for the operation of civil aviation units (CAU). In recent years, with the widely promotion of safety management system (SMS) in civil aviation, the operation of safety performance has brought new task and challenge to the CAUs (International Civil Aviation Organization, 2013). An SMS defines measurable performance outcomes to determine whether the system is truly operating in accordance with design expectations and not simply meeting regulatory requirements. In SMS, the safety performance indicators (SPIs) are used to monitor known safety risks, detect emerging safety risks and to determine any necessary corrective actions. The Federal Aviation Administration (FAA) publishes the performance and accountability report every year (Federal Aviation Administration, 2014). European Organisation for the Safety of Air Navigation (Eurocontrol) annually releases the performance review report on the assessment of air traffic management (ATM) in Europe (Eurocontrol, 2014). The FAA and Eurocontrol also jointly provide the comparison of ATM-related operational performance of U.S. and Europe yearly (FAA & EUROCONTROL, 2014). In the academic field, Luo developed the risk assessment model and procedures for ATM (Luo et al., 2009a, 2009b). Shyur proposed a quantitative model for aviation safety risk assessment, where the model used data on both accident and safety indicators to quantify the aviation risk which are caused by human errors (Shyur, 2008). Lee developed a quantitative model for assessing aviation safety risk factors as a means of increasing the effectiveness of safety risk management system by integrating the fuzzy linguistic scale method, failure mode, effects and criticality analysis principle (Lee, 2006).

In spite of plenty of standards, specifications and papers on SMS released by civil aviation organizations and scholars, these documents mainly focus on hazard identification and risk control, lacking of a detailed method for CAU's SPI monitoring and safety performance measurement. In this paper, a specific method is proposed for safety performance measurement based on the analytic hierarchy process (AHP) and Delphi method, called the DAHP model, providing the basement for CAU's safety management. The remaining of this paper is organized as follows. In Section 2, the DAHP model is described in detail. Then, Section 3 describes the standards for the SPI monitoring and measurement, and in Section 4, a case is discussed on the safety performance process of a regional CAU in China. Some conclusions close the paper in Section 5.

2. The DAHP model

In this section, the traditional AHP model is introduced firstly, and then the Delphi method is proposed to estimate the element values of the comparison matrix of the AHP model with the support of expert knowledge. Finally, the AHP and the Delphi method are combined, called the DAHP model, to measure the safety performance quantitatively.

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2.1. AHP

The method of AHP is based on the idea that a complex problem can be effectively examined if it is hierarchically decomposed into its components (Saaty, 1980, 2008). Thus, AHP provides a holistic view of the problem. AHP begins with the top level in the hierarchy that reflects the main objective. An element at a higher level of the hierarchy is said to be the governing element for those elements at the lower level. Elements at a certain level are compared against each other with reference to their effect on the governing element. Let us consider the elements E_1, E_2, …, E_n of some level in a hierarchy and denote their normalized weights by w_1, w_2, …, w_n, respectively. The value of w_i reflects the degree of importance of the E_i element. The first step in the calculation of w_i is to derive pairwise comparisons between the n elements. These pairwise comparisons are structured into an $n \times n$ matrix called a comparison matrix

$$\mathbf{A} = \begin{array}{c} \\ E_1 \\ E_2 \\ \vdots \\ E_n \end{array} \begin{array}{c} \begin{array}{cccc} E_1 & E_2 & \dots & E_n \end{array} \\ \begin{bmatrix} a(1,1) & a(1,2) & \dots & a(1,n) \\ a(2,1) & a(2,2) & \dots & a(2,n) \\ \vdots & \vdots & & \vdots \\ a(n,1) & a(n,2) & \dots & a(n,n) \end{bmatrix} \end{array}. \quad (1)$$

Elements of the matrix **A** can be derived using a nine-scale approach. The values of $a(i, j)$ represent the importance comparison between the elements of E_i and E_j. More specifically, the value of $a(i, j)$ is set to 1, 2, 3, …and 9. Also, $a(j, i) = 1/a(i, j)$ for all $j = 1, 2, \dots, n$. In the nine-scale approach, if the element of E_i is more important than E_j, the value of $a(i, j)$ is set to 2, 3, …and 9. Conversely, if the element of E_i is more important than E_j, the value of $a(i, j)$ is set to 1/2, 1/3, …and 1/9. In case that the importance of the two elements are the same, the value of $a(i, j)$ is set to 1. The weight of E_i, w_i, is the averaged and normalized value of all the elements in its row of the matrix **A**.

2.2. The Delphi method

The Delphi method is a structured communication technique, originally developed as a systematic, interactive forecasting method which relies on a panel of experts (Linstone and Turoff, 1975). In the standard version, the experts answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. It is believed that during this process the range of the answers will decrease and the group will converge towards the "correct" answer. Finally, the process is stopped after a pre-defined stop criterion and the mean or median scores of the final rounds determine the results. Two key issues of the Delphi method in performance measurement are discussed in the following paragraphs, including the design of expert questionnaire and the selection of experts.

In the expert questionnaires, the background knowledge of safety performance measurement is introduced firstly and then the Delphi method. Setting of the element values in the comparison matrices on all the levels is the main content. Additional questions are required to answer on the SPI rating standards, which is the score deduction standard in this paper. Moreover, suggestions should also be provided for the SPI selections.

Expert selection is another significant issue in the Delphi method, which should follow the principles of authority and universality. The experts should cover the specific fields of civil aviation, such as the operators of airlines, airports and air traffic service (ATS). The number of experts should also be properly set. A small number restricts the representativeness in subjects and area, while a large one results in management difficulties. Generally, it is suitable to invite 10–20 experts to answer the questionnaires.

2.3. DAHP

With the combination of the Delphi method and AHP, the DAHP model can take full advantage of the expert knowledge and quantitative calculation, overcoming the poor authority in the simple use of AHP. In this paper, the CAU SPIs are arranged on a three-level DAHP model. The weights of the former two levels could be estimated by the AHP method, where the element values of the comparison matrix on every level are estimated by the experts with the Delphi method.

Therefore, the synthetic weights of the sub-SPIs on the second level w_{ij}^{1-2} are calculated as

$$w_{ij}^{1-2} = w_i^1 \times w_j^2 \quad (2)$$

where w_i^1 denotes the weight of the indicator i on the first level, and w_j^2 denotes the weight of the indicator j on the second level belong to the indicator i on the first level. The weights of all the SPIs on the former two levels are estimated by the Delphi method described in Subsection 2.2. On the third level, the weights of all the indicators are equal in value. Then, all the weight elements are arranged in the weight vector $\mathbf{W}^{1-2}$. The details of the three-level DAHP model will be discussed in Section 3.

3. Safety performance measurement method

Safety performance results provide objective evidence for the regulator to assess the effectiveness of the CAU's SMS and to monitor achievement of its safety objectives. The CAU's SPIs should consider factors such as the safety consequences (result indicators), safety management and safety operation (process indicators), which are selected and developed in consultation with the CAU's regulatory authority. In this section, we propose a method for CAU's safety performance monitoring and measurement. The SPIs and associated targets should be accepted by the regulator responsible for the CAU's authorization, certification or designation. In Subsection 3.1, the SPI scores are measured with the proposed standard. Then, in Subsection 3.2, after the score measurement, all the SPIs are arranged in a three-level DAHP model framework to calculate the safety performance. In the three-level DAHP model, the safety performance indicators are arranged on a three-level framework. The weights of the indicators on each level are calculated with the comparison matrix of AHP, while the elements of the comparison matrix are decided by the experts after two or more rounds with the Delphi method.

3.1. SPI monitoring

In practice, the safety performance of an SMS could be expressed by quantitative SPIs on the third level of the DAHP model and their corresponding alert and target values. The CAU should monitor the performance of safety target indicators in the context of historical trends to identify any abnormal changes in safety performance. Likewise, target and alert settings should take into consideration of recent historical performance for a given indicator. Desired improvement of targets should be realistic and achievable for the CAU.

The target setting is a desired percentage improvement (in this case 5%) over the previous year's data point average. The